

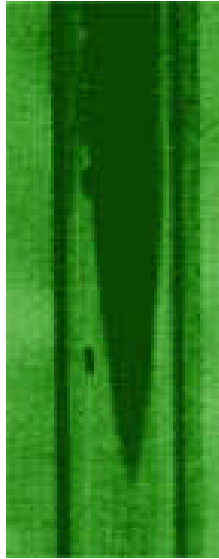
# Novel Shapes of Miscible Interfaces Observed

The dynamics of miscible displacements in a cylindrical tube are being investigated experimentally and numerically, with a view to understand the complex processes that occur, for example, in enhanced oil recovery, hydrology, and filtration (refs. 1 and 2). We have observed complex shapes of the interface between two liquids that mix with each other when the less viscous liquid is displaced by the more viscous one in a tube.

A less viscous fluid that displaces a more viscous fluid is known to propagate in the form of a "finger," and a flight experiment proposed by Maxworthy et al. (ref. 3) to investigate the miscible-interface dynamics is currently being developed by NASA.

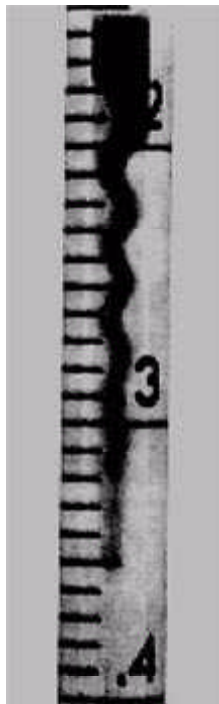
From the current theory of miscible displacements, which was developed for a porous medium satisfying Darcy's law (see ref. 1), it can be shown that in the absence of gravity the interface between the fluids is destabilized and thus susceptible to fingering only when a more viscous fluid is displaced by a less viscous one. Therefore, if the interface is initially flat and the more viscous fluid displaces the less viscous fluid, the interface ought to be stable and remain flat. However, numerical simulations by Chen and Meiburg (ref. 4) for such displacement in a cylindrical tube show that the interface is unstable and a finger of the more viscous fluid is indeed formed.

Preliminary experiments performed at the NASA Glenn Research Center show that not only can fingering occur when the more viscous fluid displaces a less viscous one in a cylindrical tube, but also that under certain conditions the advancing finger achieves a sinuous or snakelike shape. These experiments were performed using silicone oils in a vertical pipette of small diameter. In the initial configuration, the more viscous fluid rested on top of the less viscous one, and the interface was nominally flat. A dye was added to the upper liquid for ease of observation of the interface between the fluids. The flow was initiated by draining the lower fluid from the bottom of the pipette, at speeds less than 0.1 mm/sec.



*Formation of an axisymmetric finger; viscosity ratio, 2.*

When the upper fluid was twice as viscous as the lower fluid, an axisymmetric finger of the more viscous fluid was observed to form (see the preceding figure). When the viscosity ratio was 10, the steady-state shape attained by the interface was not axisymmetric. Rather, the upper liquid had a sinuous shape as it flowed down the pipette (see the following figure).



*Sinuous shape of the interface; viscosity ratio, 10.*

This study is ongoing. We plan to modify our apparatus so that the more viscous fluid can be injected from either end of the tube. This will not only enable better control of the displacement in comparison to the draining technique we have used, but also ascertain the

role played by buoyancy forces in the experiments. We plan to vary the viscosity ratio and the volumetric flow rate in the tube, while maintaining as small a density difference between the fluids as possible.

## References

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4. Chen, C.Y.; and Meiburg, E.: Miscible Displacements in Capillary Tubes. 2-- Numerical Simulations. *J. Fluid Mech.*, vol. 326, 1996, pp. 57-90.

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**Headquarters program office:** OBPR

**Programs/Projects:** Microgravity Science